# Theory Reach of BigBOSS

## *with comparison to JDEM-PS and BigBOSS variations*

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**based on "Testing Standard Cosmology with Large Scale Structure"**

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# Cosmic Structure

Galaxy 3D distribution or power spectrum contains information on:

- Growth - evolving amplitude
- Matter/radiation density, H - peak turnover
- Distances - Baryon acoustic oscillations
- Growth rate - redshift space distortions
- Neutrino mass, non-Gaussianity, gravity, etc.

**BigBOSS:** it's not a BAO survey, it's a Cosmic Structure survey.

# Data, Data, Data

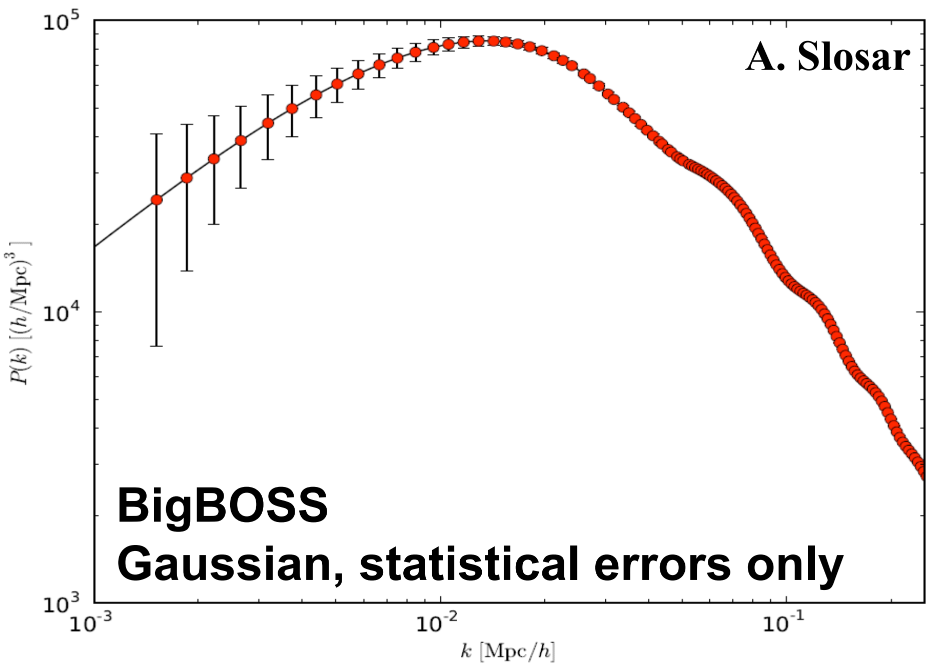
As wonderful as the CMB is, it's 2-dimensional.

The number of modes giving information is $l(l+1)$ or **~10 million**.

BOSS (SDSS III) will map **400,000** linear modes.

BigBOSS will map **15 million** linear modes.

Information increases as $k^3$ not $l^2$. If we can understand beyond the linear regime…



# Testing Cosmology with Structure

$$P(k,\mu) = (b + f\mu^2)^2 \, P_{\rm lin}(k)$$

**Galaxy bias** $\delta_g = b\,\delta_m$

**Growth** $P_{\rm lin}(k) = \left\langle \left(\frac{\delta\rho}{\rho}\right)_k^2 \right\rangle \sim D^2(a)$

**Redshift anisotropy** $\mu = k_{||}/k$

**Growth rate** $f = \frac{d\ln D}{d\ln a} \sim \Omega_m(a)^\gamma$

**Cosmological parameters affect D(a), $\Omega_m$(a)**

**Gravity characterized by growth index $\gamma$.**

$$D(a) \approx a \exp\{ \int_0^a d\ln a\, [\Omega_m(a)^\gamma - 1] \}$$

# Testing Cosmology with Structure

**The most growth occurs the latest, i.e. low z. The growth rate $f=\Omega_m(a)^\gamma$ also most sensitive at low z.**

**Can we do power spectrum (including BAO) measurements from the ground, rather than space? How does BigBOSS stack up against "JDEM-PS"?**

**Must include main physics affecting growth:**

**$\gamma$ - Gravity theory (test GR – $\gamma_{DE}$=0.55-0.56)**

**$w_0$, $w_a$ - Dark energy effects on expansion history**

**$m_\nu$ - Neutrino mass (free stream/anticlustering)**

# Survey Comparison

| BigBOSS | LRG[a] | EL |
|---|---|---|
| $z$ range | $0-1$ | $1-2$ |
| $\Omega_{\rm sky}$ (deg$^2$) | 24000 | 24000 |
| $\bar{n}$ $(h/{\rm Mpc})^3$ | $3.4\times10^{-4}$ | $3.4\times10^{-4}$ |
| $b$ | 1.7 | $0.8-1.2$ |
| $R$ | $\geq 2300$ | $\geq 2300$ |

| JDEM-PS | LRG[a] | EL |
|---|---|---|
| $z$ range | $0-0.7$ | $0.7-2$ |
| $\Omega_{\rm sky}$ (deg$^2$) | 10000 | 20000 |
| $\bar{n}$ $(h/{\rm Mpc})^3$ | $3.4\times10^{-4}$ | $19.5\times10^{-4}$ |
| $b$ | 1.7 | $0.8-1.2$ |
| $R$ | $\approx 2000$ | $\geq 200$ |

galaxy redshift survey

TABLE I: Survey specifications for the Stage IV experiments BigBOSS and JDEM-PS. [a]Uses northern hemisphere (10000 deg$^2$) LRG $z=0-0.7$ from BOSS [25].

**Does not include QSO part of BigBOSS.**
**Will later consider variations on baseline BigBOSS.**

# Multiple Probes

**Multiple techniques are not just a good idea, they are essential.**

**Global correlation coefficient measures total degeneracy.**

$$r_i = \sqrt{1 - \frac{1}{F_{ii}\,(F^{-1})_{ii}}}$$

$$r_{\rm BigBOSS} = \begin{pmatrix} 0.9954 \\ 0.9943 \\ 0.9911 \\ 0.9933 \\ 0.9993 \\ 0.9893 \\ 0.9990 \\ 0.9997 \\ 0.9996 \end{pmatrix} \; ; \quad r_{\rm JDEM\text{-}PS} = \begin{pmatrix} 0.9970 \\ 0.9608 \\ 0.9960 \\ 0.9908 \\ 0.9994 \\ 0.9895 \\ 0.9988 \\ 0.9997 \\ 0.9996 \end{pmatrix}$$

TABLE IV: Vectors of the global correlation coefficients for the parameters $(\gamma, b_{LRG}, b_{EL}, \Omega_{DE}, \Omega_\nu, \omega_b, h, w_0, w_a)$ for BigBOSS and JDEM-PS.

**Strongest complementarity is with Supernovae, especially if fiducial is not $\Lambda$CDM.**

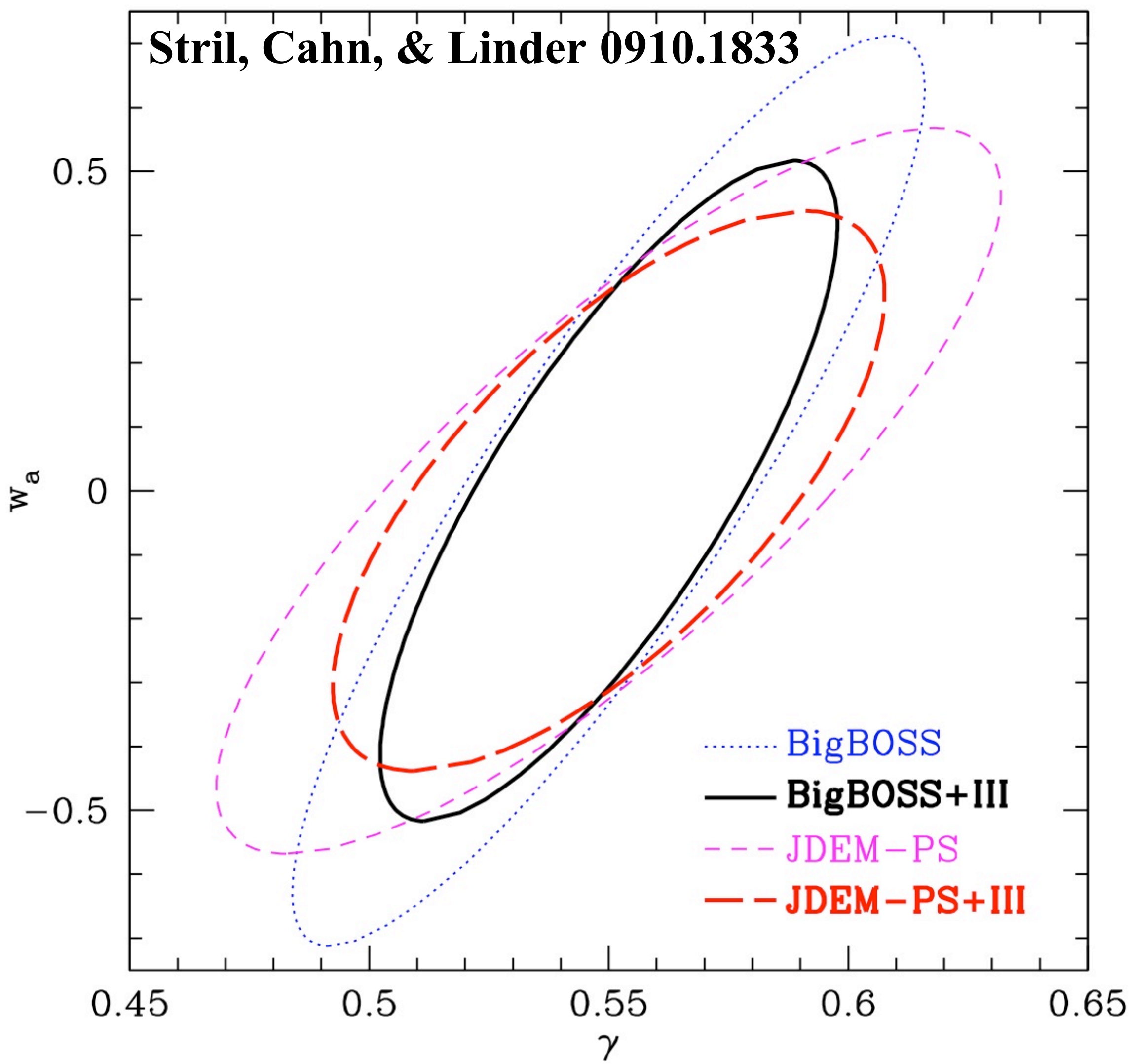
# Cosmology Fit

**9 parameter fit, Fisher matrix estimation.**

**Includes key parameters affecting growth.**

1. $\gamma = 0.55$, gravitational growth index
2. $b_{LRG}$, the bias for LRG (see Table I)
3. $b_{EL}$, the bias for EL (see Table I)
4. $\Omega_{DE} = 0.744$, dark energy density today
5. $\Omega_{\nu} = 0.002$, massive neutrino energy density today
6. $\omega_b = \Omega_b h^2 = 0.0227$, reduced baryon energy density today
7. $h = H_0/(100\ \mathrm{km/s/Mpc}) = 0.719$, reduced Hubble constant
8. $w_0 = -0.99$, dark energy equation of state today
9. $w_a = 0$, dark energy equation of state time variation

# Testing Standard Cosmology




**9 parameter fit** Stril!

**BigBOSS can test GR**

**$\gamma = 0.55 \pm 0.03$**

**Good complementarity with SN, WL, CMB on dark energy.**

**As good as space!**

**N.B. Ignoring neutrino mass overestimates constraint power by a factor of 3-4.**

# Ground vs. Space

**As good as space!**

**BigBOSS is superior to JDEM-PS in testing gravity:**

| | BigBOSS | JDEM-PS | BigBOSS+III | JDEM-PS+III |
|---|---|---|---|---|
| $\sigma(\gamma)$ = | 0.043 | 0.054 | 0.031 | 0.038 |

**BigBOSS is superior/comparable to JDEM-PS in testing all dark cosmology:**

**FOM Ground/Space**
**confidence contour inverse-area ratio**

| | BigBOSS/JDEM-PS | $\text{BigBOSS}_{+\text{III}}/\text{JDEM-PS}_{+\text{III}}$ |
|---|---|---|
| $\gamma, \Omega_{\rm DE}$ | 0.93 | 0.99 |
| $\gamma, w_0$ | 1.16 | 1.20 |
| $\gamma, w_a$ | 1.21 | 1.23 |
| $w_0, w_a$ | 0.88 | 0.86 |

# Nonlinear Regime

Remember the $k^3$ advantage in number of modes. We need to understand beyond the nonlinear power spectrum.

For BAO aspects, see **Padmanabhan & White 0906.1198, Seo et al. 0910.5005**

Nonlinearities affect redshift anisotropies $(b+f\mu^2)^2$ factor from large scale velocities, and damping factor from small scale anisotropies.

$$\begin{aligned} \text{Cutoff:}\ P_{nl}(k,\mu) &= P(k,\mu)\,\Theta(k_+ - k) \\ \text{Gaussian:}\ P_{nl}(k,\mu) &= P(k,\mu)\,e^{-(k/k_+)^2\mu^2} \\ \text{Lorentzian:}\ P_{nl}(k,\mu) &= \frac{P(k,\mu)}{1+(k/k_+)^2\mu^2} \end{aligned}$$

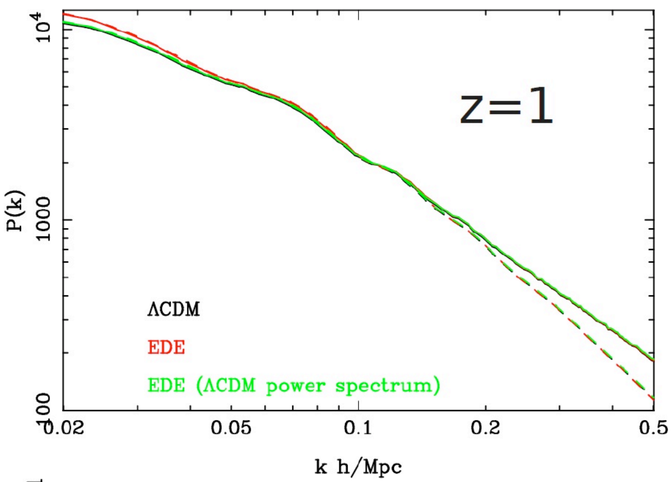
| Case | BigBOSS | JDEM-PS |
|---|---|---|
| Cutoff | 0.043 | 0.054 |
| Gaussian | 0.024 | 0.026 |
| Lorentzian | 0.019 | 0.021 |

$\sigma(\gamma)$

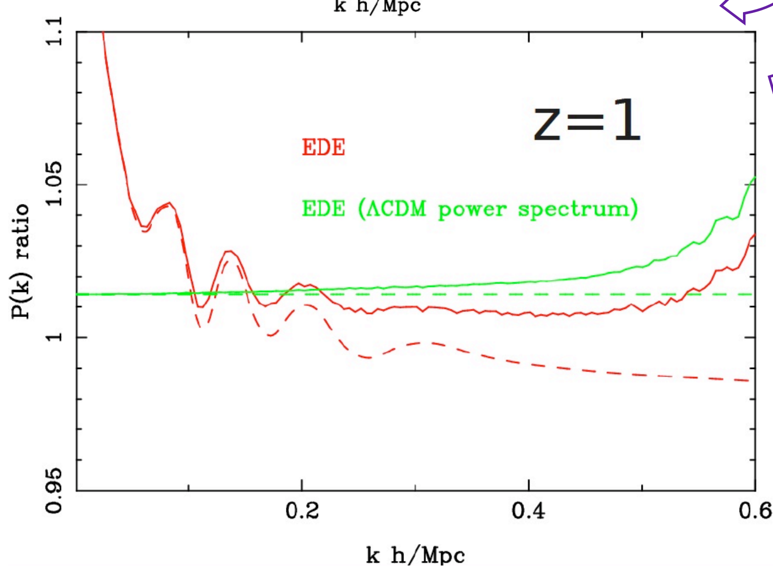
# Nonlinear Regime, non-ΛCDM

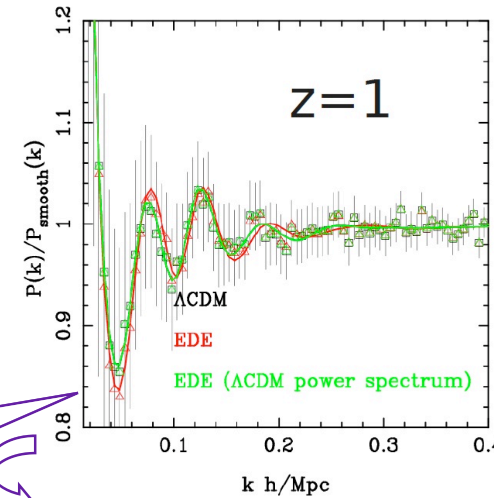
**Matt Francis studied BAO scale and $P_k$ in Early DE models with N-body simulations.**

**Nonlinear (translinear) scales remarkably insensitive to EDE.**



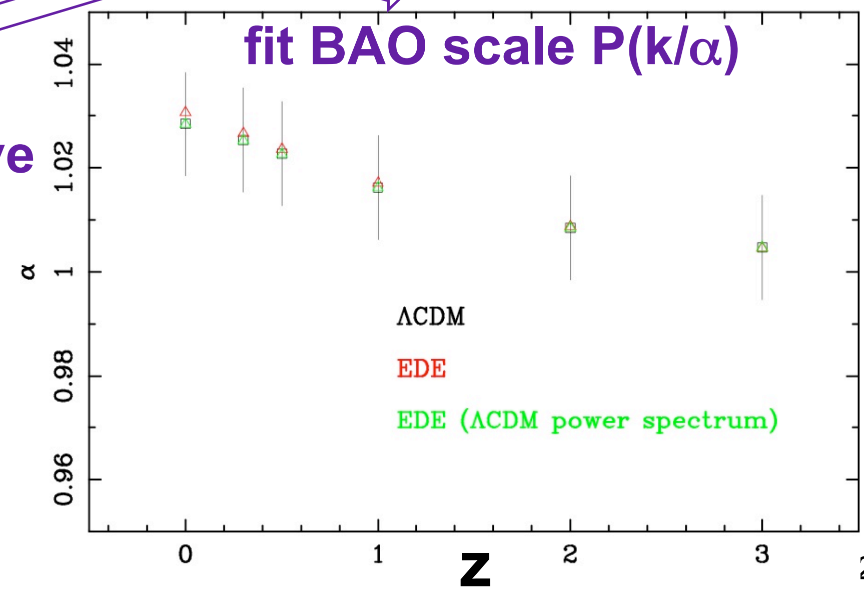

ratio




BAO: remove smooth fit

fit BAO scale P(k/α)



# Redshift Range

Since D(a), $f=\Omega_m(a)^\gamma$ strengthen at lower redshift, consider BigBOSS variation: emission line galaxy sample at z=0.7-1.7 rather than z=1-2.

This would reduce technical complexity (NIR detectors) and line confusion.

Result: No harm, and even ~10% improvement in cosmology estimation ($\gamma, w_0, w_a$).

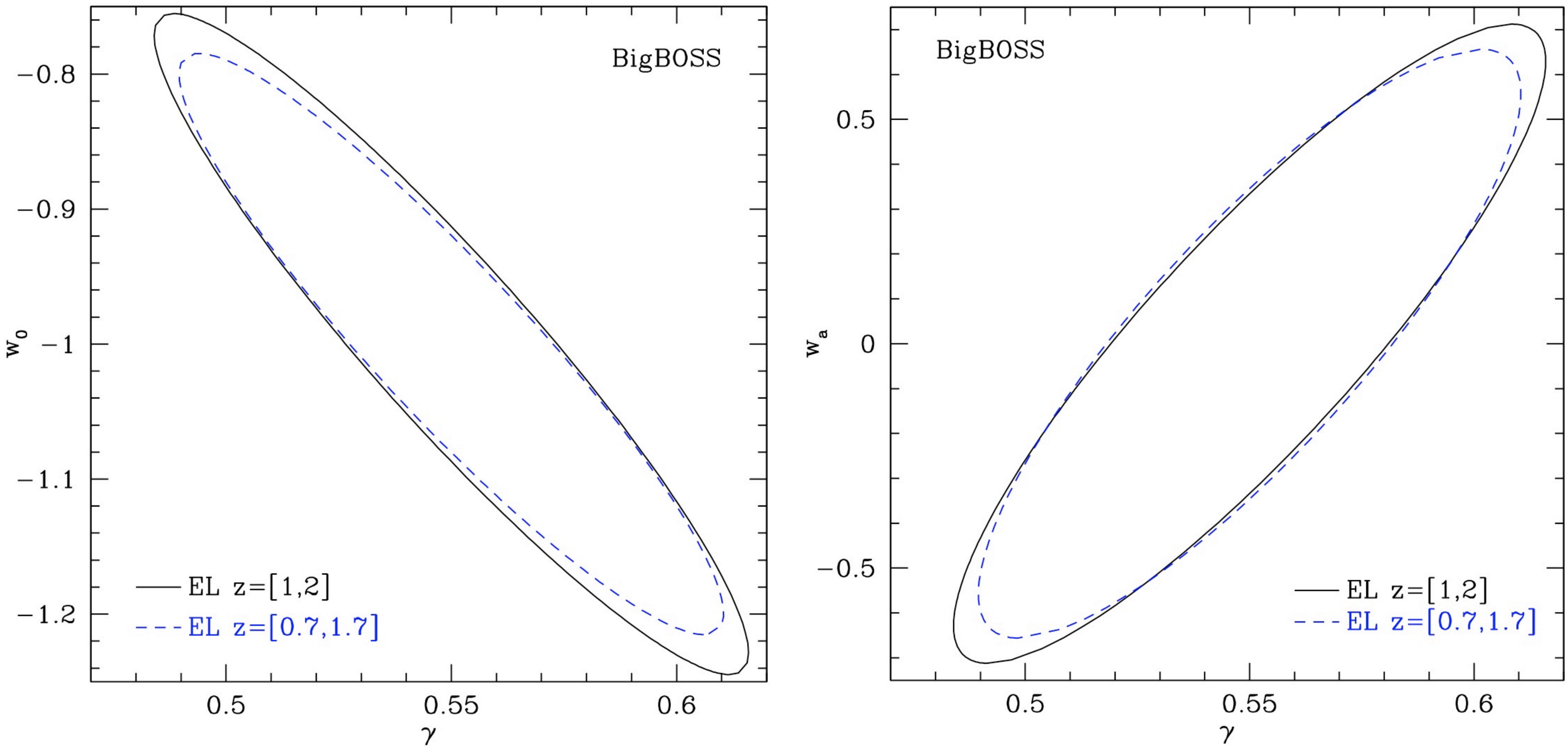
Overlap with LRG allows extra gain for higher n.

$z_{EL}$=[0.7,1.7] vs. $z_{EL}$=[1,2] has $\sigma(\gamma)$=0.0398 vs. 0.0435

$w_0$-$w_a$ FOM improves by 6%

# Redshift Range

## $z_{EL}$=[0.7,1.7] improves by 9% in $\gamma$, $w_a$ and 14% in $w_0$.



# Number Density

With shifted redshift window giving better S/N could trade for higher number density.

Trade Study: consider 4 x $n_{ELG}$ for z=0.7-1.

(Motivated by Seljak's sample variance suppression for nP>1 with multi-bias sample)

Results: 2-4% further gain on $\sigma(\gamma)$, $\sigma(w_0)$, $\sigma(w_a)$.

However, worth exploring for other n-z combinations or other ways of using time saved.

# Summary

BigBOSS is more than BAO. It provides an excellent test of gravity ($\gamma$), and strong complementarity with other dark energy missions.

Very important to simultaneously fit expansion ($w_0$,$w_a$), neutrino mass ($m_\nu$), gravity ($\gamma$).

As good as space JDEM-PS!
(and this is before including BigBOSS' Ly$\alpha$ data).

Redshift range z=0.2-1.7 very strong, retires risk and cost.

Ready for detailed trades on galaxy number density and redshift.